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San Francisco Bay Area National Urban Runoff Project. Demonstration of Non-Point Source Pollution Management on Castro Valley Creek: Executive Summary

Alameda County Flood Control and Water Conservation District, Hayward, CA

Prepared for

Association of Bay Area Governments
Berkeley, CA

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SAN FRANCISCO BAY AREA
NATIONAL URBAN RUNOFF PROJECT

A Demonstration of Non-Point Source
Pollution Management on
Castro Valley Creek

EXECUTIVE SUMMARY

Prepared for

U.S. Environmental Protection Agency
Water Planning Division
Washington, D.C. 20460

June 1981

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This report presents the results and conclusions from an EPA-sponsored nonpoint source pollution management project on Castro Valley Creek in Castro Valley, CA, designed to correlate street cleaning and urban runoff water quality. The study area was a suburban 1,542-acre watershed that is considered typical of many residential basins in the San Francisco Bay region. To demonstrate the relationship between street cleaning and runoff, the project was designed to measure the following: (1) street cleaning effectiveness (2) street surface pollutant loadings and (3) runoff water quality. Data were analyzed to correlate street surface pollutant loadings before rain events with changes in runoff water pollution mass yields. The Executive Summary presents an overview of the project. It is designed to be a complete (yet abbreviated) report with information especially pertinent to local public works officials.

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SAN FRANCISCO BAY AREA
NATIONAL URBAN RUNOFF PROJECT

A Demonstration of Non-Point Source
Pollution Management on
Castro Valley Creek

EXECUTIVE SUMMARY

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DISCLAIMER

This report has been reviewed by the Water Planning Division, U.S. Environmental Protection Agency, and the Alameda County Flood Control and Water Conservation District and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This report presents the results and conclusions from the EPA-sponsored non-point source pollution management project on Castro Valley Creek in Castro Valley, CA. Non-point pollution in some areas represents a major obstacle to achievement of the goal of the 1972 Federal Water Pollution Control Act Amendments. This was the first prototype project to be part of the Nationwide Urban Runoff Program (NURP) and was designed to correlate street cleaning and urban runoff water quality.

The study area was a suburban 1,542-acre watershed that is considered typical of many residential basins in the San Francisco Bay region. To demonstrate the relationship between street cleaning and runoff, the project was designed to measure the following: (1) street cleaning effectiveness (2) street surface pollutant loadings and (3) runoff water quality. Data were analyzed to correlate street surface pollutant loadings before rain events with changes in runoff water pollutant mass yields.

The project also investigated two other related subjects: One was a comparison of the performance of regenerative air (RA) and mechanical street cleaning equipment. It was determined that the RA equipment was more effective than the mechanical equipment only under very clean street surface conditions. The other subject involved assessing the magnitude and severity of asbestos pollution in urban areas and waters. It was found that there are substantial quantities of asbestos on street surfaces and in urban runoff but the current limited water quality criteria does not provide a basis for determining if there is a problem. Automobiles appear to be an important source of street surface asbestos.

As a result of two years of effort, this project demonstrated that street cleaning can effect a substantial reduction in the amount of lead and total solids, as measured in the runoff water. A maximum of thirty-five percent (35%) of lead and twenty percent (20%) of total solids can be prevented from entering the runoff by very frequent street cleaning (greater than 3 passes per week). Information on the effectiveness of less frequent sweeping was also developed. The results of this project in conjunction with other NURP street cleaning projects will help identify the role of street cleaning in meeting the goals of the 1972 Federal Water Pollution Control Act Amendments.

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EXECUTIVE SUMMARY

Introduction

- This document is the final report of a study conducted to develop information on the control of urban runoff and the potential impacts on water quality.
- The study focused on a small urban feeder creek in the San Francisco Bay Area: Castro Valley Creek.
- The work was performed by Alameda County Flood Control and Water Conservation District (ACFC&WCD) and the U.S. Geological Survey (USGS), with technical guidance by Woodward-Clyde Consultants.
- Funding support came from Alameda County Flood Control and Water Conservation District (ACFC&WCD), U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS).
- Administrative support was provided by the Association of Bay Area Governments (ABAG), by coordinating grant arrangements.
- Technical review and comment were provided by representatives from the U.S. Army Corps of Engineers (CORPS), the U.S. Geological Survey and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB).
- The study focused on developing basic technical information which local decision-makers need to formulate strategies for urban runoff control.
- The study is an important component of EPA's Nationwide Urban Runoff Program (NURP) to help identify the role of street cleaning as a measure to control non-point pollution from urban streets.

The report consists of 8 sections and 9 supportive appendices arranged as follows:

The Executive Summary presents an overview of the project. It is designed to be a complete (yet abbreviated) report with information especially pertinent to local public works officials. The summary is arranged as follows:

The Background presents technical perspective on urban runoff with a discussion of contributions from pollutant source areas which is germain to understanding the approach and findings reported herein. It also presents the study's objectives and methodology. The Conclusions portion presents the principal questions which the project sought to answer and summarizes the major findings in the form of answers to the questions.

The remaining sections discuss the interpretation of the data collected on the receiving water, the street cleaning and a strategy for control of urban runoff. The appendices basically present the actual data collected.

Background

In water pollution terminology, sources of pollutants are considered either point sources or non-point sources. Point sources are those that discharge pollutants at a single, easily identifiable location; e.g., municipal and industrial treatment plant discharges. Non-point sources are diffused sources and are those that discharge at many locations; e.g., storm water runoff.

Most of the Federal, State and local water quality control efforts to date have been directed at point sources. Lack of past attention to non-point sources leaves them as a major obstacle for obtaining water quality goals. Governments at all levels need to determine whether the control of non-point sources, such as urban runoff from street surfaces, will provide greater receiving water benefits at less cost than additional control of point sources; e.g., municipal sewage treatment.

Past research has revealed the substantial water pollution potential of street surface contaminants (Sartor and Boyd, 1972). Although it is quite clear that street dirt pollutants have a significant effect on the quality of receiving waters, questions remain about the cost and effectiveness of street cleaning. Information on the cost and effectiveness is necessary in order to help demonstrate the potential role of street cleaning for the management of water quality in order to help meet the swimmable, fishable waters goal of the Federal Water Pollution Control Act Amendments, Public Law (PL) 92-500.

Contributions from Pollutant Source Areas

Many sources in the urban area are recognized as being contributors of urban runoff pollutants. Street surfaces are urban source areas that are quite important because they contribute significant quantities of several heavy metals and asbestos, whereas oxygen demanding materials and nutrients are believed to originate mostly from landscaped areas and areas of vacant land. Vacant and landscaped areas tend to be among the most permeable surfaces in an urban area, tend to be located farthest from the storm sewerage system and also contribute little flow during an urban runoff event to the receiving water. Therefore, very little of potential pollutant yields reach the storm sewer outfalls into Castro Valley Creek.

Roof tops are also located at relatively long distances from the storm sewers. Because roof tops are not directly connected to the storm sewerage system, their pollutant yield to the receiving waters is very small. Street surfaces on the other hand are located close to the storm drainage system and are almost totally impermeable. Most of the runoff that originates from street surfaces is expected to reach the receiving water.

The amount of pollutants in urban runoff depends (in part) upon the size and frequency of rain events. Stated simply:

- Larger events are capable of removing and transporting greater amounts of pollutants from their source areas to the receiving waters.

- The less frequent the events the more time is available for pollutants to accumulate on the source areas.

It is estimated that, if all of the total particulate pollutants deposited in the study area portion of the Castro Valley Creek watershed were totaled, only about 30 percent would reach Castro Valley Creek via urban runoff. Also, it is estimated that only 10 percent of the nutrients and oxygen demanding materials deposited in the contributing area would reach the creek. On the other hand, most of the heavy metals in the area would be expected to reach the creek. These differences are related to the fact that the remaining pollutants (i.e., those that are washed off the source areas but do not reach the outfall) tend to be trapped or otherwise accumulate in other areas in the urban environment. The most significant areas of accumulation are the soils, vegetation, and possibly groundwater.

Objectives

The study described herein was directed towards developing information on three subjects which were of particular concern to local decision makers and the nationwide urban runoff program. The objectives were to:

1. Demonstrate the effectiveness of street cleaning in improving water quality.

2. Provide information to local Public Works Agencies on how to incorporate water quality as a factor into their street cleaning programs.

3. Investigate the quantities of asbestos on urban streets and in urban runoff.

Again, the primary purpose of the project was to demonstrate whether removing the pollution load from street surfaces by street cleaning has an affect on urban runoff quality from street surfaces. The project collected data to compare the monitored mass pollutant flows of the storms with the total pollutant removal of street cleaning programs. A valid data set for this analysis consists of a data point for a monitored runoff event that occurs between, before and after street surface monitoring data points. During the two years of this study, 22 valid data sets were collected.

Methodology

Project field activities began in October, 1978, and ended in April, 1980. In order to demonstrate the relationship between street cleaning and runoff water quality, the project measured:

(1) street cleaning effectiveness, to identify the quantity of pollutants removed and the initial and residual loadings before and after cleaning for a variety of street cleaning programs. The street surface particulate sample was obtained by vacuuming portions of the street surfaces immediately before and after the area was cleaned. The two loadings were then compared to obtain measures of street cleaning effectiveness. These samples were then divided into eight discrete particle sizes, weighed, then composited over selected time periods by particle size and test area for chemical analyses. The resultant street surface pollutant loadings were then available for comparison;

(2) street surface pollutant accumulation rates to identify the loading on the street at any time;

(3) precipitation, to know the quantity of rainfall; and

(4) receiving and runoff water quantity and quality, to identify the quantity of pollutants washed off the watershed for various types of rainstorms. Two monitoring stations were located on Castro Valley Creek. The upper station (Seaview) measured the runoff from the rural area, and the lower station (Knox) measured the runoff from both the urban area and the rural area. The contribution from only the urban test area was determined by subtracting the contribution of the rural station from that of the lower station.

Curve fitting analyses was used to correlate street surface pollutant loadings before rain events with changes in runoff water mass yields.

Conclusions

Research funded by the Environmental Protection Agency (EPA) and the Alameda County Flood Control and Water Conservation District (ACFC&WCD) was conducted to demonstrate whether street cleaning activities can significantly affect urban runoff water pollution.

During the development of the study, the investigators formulated a series of specific questions which related directly to the previously stated objectives. The many study tasks were designed and conducted to develop answers to these questions. These questions and the conclusions of the study are listed below:

1. Question

- o To what extent is receiving water quality a function of street cleanliness?
- o Is there a problem in the receiving water?
- o How clean does the receiving water need to be?
- o What standards apply and how do they apply to wet weather beneficial uses?

Conclusion

In order for Castro Valley Creek to meet recommended water quality criteria, significant reductions in the amounts of the toxic metals lead, cadmium, copper and zinc - would be necessary during wet weather conditions.

The standard of most relevance is the aquatic life criteria (established by EPA and published in the Federal Register November 28, 1980). Beneficial uses of the creek established by the State include water contact and non-contact recreation as well as aquatic habitat. Castro Valley Creek does have a water quality problem because it conveys toxic pollutants in concentrations that exceed established standards and in large quantities into San Francisco Bay. It may be desirable to control these constituents to upgrade the water quality conditions of the creek and the more important receiving water, San Francisco Bay.

2. Question

Which pollutants can be controlled by street cleaning and to what extent?

Conclusion

A maximum of thirty-five percent (35%) of lead and twenty percent (20%) of total solids could be prevented from entering receiving waters by conducting frequent street cleaning activities. Other constituents, e.g., arsenic, chemical oxygen demand, and copper could be reduced by less than ten percent.

In a typical watershed, most of the lead available for washoff by rain events comes from street surfaces. This lead originates through the combustion of leaded gasoline in motor vehicles. Lead shows the greatest potential for control by street cleaning because the largest and almost only source of lead is from the combustion of leaded gasoline. If lead is ever removed from gasoline then this source would be nearly eliminated but lead may be used as a gasoline additive for a long time. Nutrients have less potential for control by street cleaning because there is a much larger quantity of nutrients on non-street areas (e.g., rooftops, lawns) in a watershed.

3. Question

How do alternative equipment types differ in performance?

Conclusions

Regenerative air (RA) street cleaning equipment was demonstrated to be more effective than mechanical brush type equipment, but only in areas that have very clean street surfaces.

Removals obtained by the RA equipment at the lower initial particulate loading values were substantially greater than for the standard mechanical brush street cleaner. However, under more typical (dirtier) loading conditions, the difference between these two types of equipment diminishes to insignificant levels.

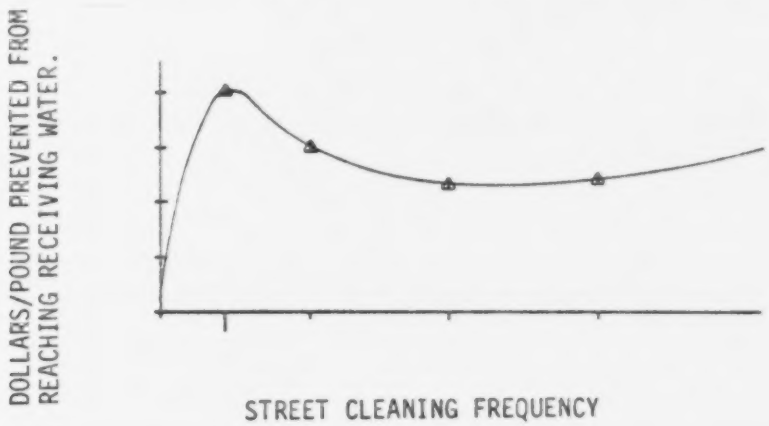
4. Question

What are the cost effectiveness relationships between street cleaning programs and receiving water quality?

Conclusion

A frequent street cleaning program may have smaller unit costs to prevent pollutants from entering receiving waters than infrequent cleaning.

Annual street cleaning costs tend to increase linearly as a function of the cleaning frequency. Further, the cost to remove a unit of pollutant from the street increases steeply with increased street cleaning. However, the cost to prevent a unit a pollutant from entering the receiving water by street cleaning does not follow an increasing unit cost pattern as shown below.



Source: Figure 1-5.

When going from a twice per month frequency to a three times per week frequency, the unit removal costs for total solids during the period of study actually decreased. Considering the weather patterns in the Bay Area, the best return for the limited street cleaning money is to clean the streets before the first rain of the year and then three times per week between the other winter storms.

5. Question

What portion of various types of pollutants are readily carried from various surfaces to receiving waters by common storms?

Conclusions

To prevent a given amount of material from entering the receiving water requires the removal from the street of ten to one hundred times that amount of material for selected contaminants.

The constituents, total solids, chemical oxygen demand, total phosphorus, orthophosphate, lead, and zinc all require the removal of about ten units of the material from the street to prevent one unit of material from entering the receiving water. Total Kjeldahl nitrogen and copper require almost one hundred times removal.

6. Question

How effective are alternative street cleaning schedules in controlling receiving water impacts?

Conclusion

A street cleaning frequency of three passes per week would provide the optimum reduction of street surface contaminants. More than three passes per week would result in little additional improvement.

7. Question

What control strategies can be used to account for the fact that large amounts of pollutants tend to accumulate in certain areas?

Conclusion

The most cost effective street cleaning strategy for preventing pollutants from entering receiving waters would be to clean the dirtiest streets more frequently than the clean streets.

It costs almost the same amount to operate street cleaning equipment on a dirty street as on a clean street. However, the same effort and money can remove much more material from dirty streets than from clean streets. To achieve the lowest unit cost removals requires cleaning the dirtiest streets more frequently than the cleaner streets. Normal municipal practice is to have the highest street cleaning frequency devoted to the downtown streets (which tend to be the cleanest). Substantial water quality improvements could be realized with no increase in budgets by changing present street cleaning objectives to consider water quality along with aesthetics.

8. Question

How does the concept of seasonal weather differences affect street cleaning strategies?

CONCLUSION

Because of the Bay Area's climatic patterns (wet winters, dry summers), a relatively intense street cleaning program should be maintained during the wet season.

The frequency of street cleaning during the different seasons is important in the various climate categories. In California, large rains can occur at the beginning of the rain season. Other times, these large rains occur later in the season with less time between storms to allow for accumulation of street surface contaminants. Large storms may contribute substantial amounts of erosion material to the streets.

9. Question

What is the cost-effectiveness of inlet cleaning compared to other control measures?

Conclusion

Based upon limited sampling, inlet cleaning appears to be a cost-effective non-point source control measure.

Because of the design of drop inlets, they receive large amounts of street dirt and debris and it is relatively easy to remove the accumulated material. Most of the material cleaned from drop inlets is prevented from reaching the receiving water, whereas a relatively smaller fraction of the material removed by street cleaning and erosion control is prevented from reaching the receiving waters. When compared to various urban runoff control measures, inlet cleaning seems to be the least costly. With the usual inlet cleaning frequency of once per year, it can only affect about two percent of the annual yield of most of the constituents. However, if it were increased to three or four times per year, inlet cleaning may prevent up to about ten percent of the contaminants from entering receiving waters. This data is based upon very limited sampling and needs further research.

10. Question

How much asbestos in urban runoff originates from man-made sources?

Conclusion

There is substantial asbestos from man-made sources on street surfaces but the current, limited water quality criteria does not provide a basis for determining if there is a problem. Automobile use appears to be an important source of asbestos associated with street dirt.

Urban Runoff & San Francisco Bay

The San Francisco Bay-Delta Estuary is the single most important water body in the State of California. More than one half of all of California's fishery resources either live in or directly depend on the Bay-Delta Estuary for their survival. San Francisco Bay also provides scenic beauty and recreation to over 5 million people who live near its shore (California State Water Resources Control Board, 1980).

San Francisco Bay is the dominant feature and primary receiving water of the Bay-Delta system. Assessment of the water quality impact on San Francisco Bay from stormwater runoff is difficult because of the drainage from its vast tributary area. The Bay-Delta system receives runoff from about 40% of the land area of California, or about 63,000 sq. mi. About 3200 sq. mi. of the region drains directly to San Francisco Bay.

The primary use of many creeks in the Bay area is to convey stormwater runoff into San Francisco Bay. Although runoff contains large amounts of pollutants, its relationship to observed water quality problems in San Francisco Bay remains uncertain. However, Castro Valley Creek's contribution of large quantities of toxic pollutants into San Francisco Bay is seen as a significant water quality problem.

As Table 1-1 shows, the two-year average concentrations of lead, cadmium, copper, and zinc measured in Castro Valley Creek during runoff events exceeded the standards set by the U.S. Environmental Protection Agency. Many receiving water average concentrations exceeded not only the 24-hour average concentration standard, but also the maximum allowable concentration criteria. Aquatic life is an established beneficial use of Castro Valley Creek.

TABLE 1-1. CONCENTRATIONS* OF METALS IN CASTRO VALLEY CREEK STORMWATER COMPARED TO AQUATIC LIFE WATER QUALITY CRITERIA

Constituent	Castro Valley Creek[1] Range	Castro Valley Creek[1] Average	Freshwater Aquatic Life Criteria[2] 24 hr. Average	Freshwater Aquatic Life Criteria[2] Maximum Concentration
Cadmium	1-12	5	.051	6.3
Copper	21-700	94	5.6	43
Lead	97-3300	488	20	400
Zinc	72-2200	325	47	570

*All units in ug/l; i.e., parts per billion (ppb).

1. Based upon measurements from October 1978 to April 1980 at the urban station; i.e., Knox Street Station; USGS No. 11181006.

2. Criteria established by EPA for pollutants designated as toxic under Section 307 (a) (1) of the Clean Water Act. These criteria were published in the Federal Register November 28, 1980. These criteria are different for various hardness conditions. Castro Valley receiving hardness is about 200 mg/l as $CaCO_3$. The criteria shown are for these hardness values.

Castro Valley Creek and many other Bay Area creeks with similar flow volumes can be considered "urban feeder creeks". These may be characterized as having low summer flows, large winter flow variations and also providing some natural habitats. It probably is not economically feasible to improve these creeks to a fishable/swimmable status.

Castro Valley, the study area for this project, is a small watershed considered typical of residential basins in the San Francisco Bay Delta Region (Sylvester, 1978). The U.S. Geological Survey and the Corps of Engineers (initially began monitoring runoff in Castro Valley in 1971) considered Castro Valley a typical residential basin because of the general geology, soils, topography, hydrology, climate, vegetation and human activities in the basin. Assessment of the impact from stormwater runoff on the water quality of Castro Valley Creek shows that the runoff water quality commonly fails to meet beneficial use criteria for several toxic heavy metals.

Although it was beyond the scope of this project to investigate the effects of street cleaning on Bay water quality, the project was based on the assumption that, if street cleaning would improve water quality in Castro Valley Creek, then street cleaning on a larger scale may improve water quality in the Bay.

Problem Definition

As a result of the P.L. 92-500, many regions of the nation undertook areawide planning studies (supported by 208 grants) to identify and define existing water quality problems. In the Bay Area, the problems investigated included fish kills, shellfish contamination, toxic pollutants, eutrophication, dredging and disposal, oil and chemical spills, and freshwater outflow from the Sacramento-San Joaquin Delta.

The following is a brief description of three of these problems and their probable causes in the San Francisco Bay Area:

o Shellfish beds are widespread, well-populated, and represent a presently under-utilized resource in San Francisco Bay. Commercial and recreational shellfish harvesting is prohibited because of contamination by bacteria, viruses and, in some cases, heavy metals. Storm runoff, sewage discharge and waste from boats are sources of contamination (ABAG, 1978).

o Many fish kill incidents can be traced to specific pollution causes, however, the fish kills occur in the Bay for unknown reasons. The State is investigating the causes of death of striped bass and has also initiated a study of the aquatic habitat of the Bay.

o There is evidence that the Bay's aquatic life may be adversely affected by toxic materials; e.g., heavy metals, pesticides and organic compounds which are showing up in analyses of Bay waters. The evidence points to pollutants that occur at low concentrations and whose effects are cumulative and/or long-term (ABAG, 1978).

Comparison of Point and Non-Point Sources

Figure 1-1 shows the expected trend and amounts of selected pollutants delivered to the Bay from different sources between 1975 and 2000. Some conclusions for 1985 that can be made from the figure are:

o Surface runoff contributes more than 20% of the total biochemical oxygen demand (BOD) to the Bay. Short-term biochemical oxygen demand (BOD) is a measure of organic material in the water readily available to bacteria as food.

o A substantial part of the heavy metal load, as well as other toxicants, is associated with the suspended solids. Surface runoff contributes more that 20% of the total suspended solids to the Bay excluding Delta outflow. Total suspended solids is solid material which is able to remain in suspension, even in still water.

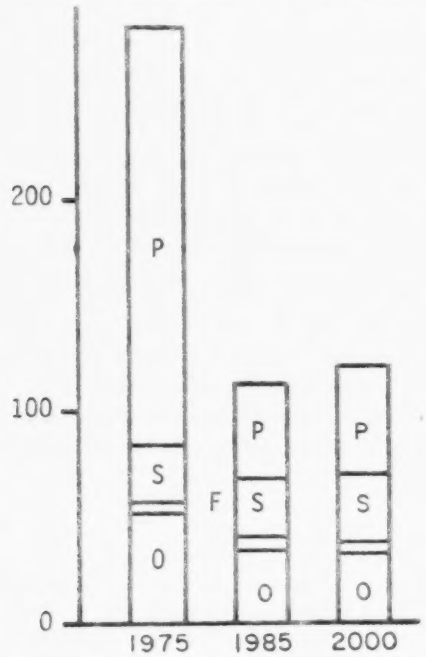
o Surface runoff contributes more than 35% of the total equivalent heavy metals to the Bay excluding Delta outflow. Total equivalant heavy metals is a weighted composite measure of the amounts of eignt reasonably common toxic metals.

A comparison between urban runoff average concentrations and treated sanitary sewage effluent point source average concentrations shows that the concentrations of heavy metals, suspended solids, and biochemical oxygen demand, are all higher in the runoff than the treated sanitary sewage effluent. Therefore, urban runoff may have more important short-term effects on San Francisco Bay than treated sanitary sewage effluent.

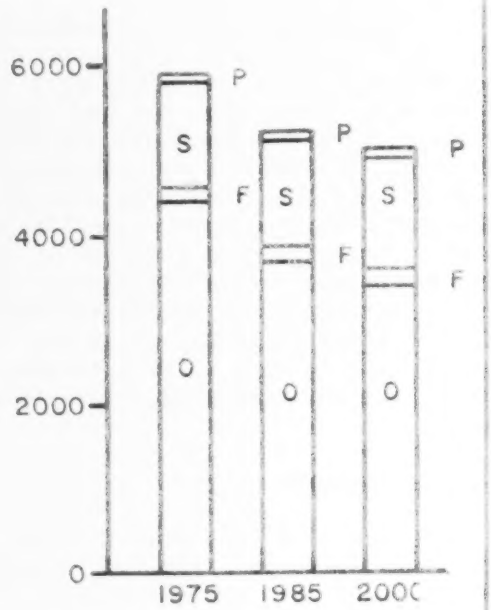
The annual amounts for the different pollutant sources indicate potential long-term problems. However, the cause-and-effect relationships between these waste discharges and problems in the receiving water is often poorly understood. The short-term effects of urban stormwater runoff on receiving waters occur (by definition) during and immediately following a runoff event: short-term effects are associated with instantaneous concentrations.

The above discussion is significant in that for a receiving water affected by both point source and non-point source pollutants, additional improvements in treatment of point sources may not be as cost-effective as additional control of non-point sources, particularly urban runoff. This is especially true for lead, because urban runoff contributes most of the lead discharged into San Francisco Bay. If non-point source pollution could be controlled, it may insure that the benefits of the billions of dollars being expended for point source controls will be fully realized in terms of fishable, swimmable waters (Congressional Research Service, November 1980).

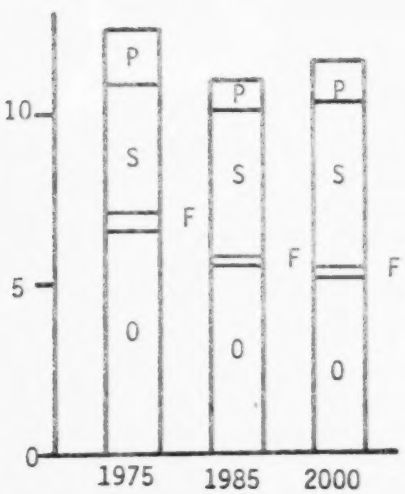
FIGURE 1-1 SOURCES OF POLLUTANTS ENTERING SAN FRANCISCO BAY.



BIOCHEMICAL OXYGEN DEMAND
(Millions of pounds per year)



TOTAL SUSPENDED SOLIDS
(Milions of pounds per year)



TOTAL EQUIVALENT HEAVY METALS
(Millions of pounds per year)

LEGEND:

P = Point sources (municipal and industrial discharges)
S = Surface runoff
F = Fallout over bay from the atmosphere (rainfall & dust fall)
O = Outflow from Sacramento-San Joaquin Delta to bay. Pollutant loadings in this category very approximate. A surface runoff component is included within the Delta outflow category.

Source: ABAG,1978

Description of Study Area

Castro Valley is an unincorporated community within Alameda County. The project's study area (Figure 1-2) was a 2.4 square mile portion of this unincorporated area. The study area was 1542 acres with primarily residential land use with urban, suburban and rural terrain. The uppermost portion of the watershed (above Seaview Gaging Station) consists of about 633 acres of rural area which is slowly being replaced with suburban residential development. This portion of the study area also has the most topographic relief. The change in elevation from the upper runoff monitoring station to the lower Knox Gaging Station (a distance of 2.4 miles) is about 200 feet. The 909 acres of urban study area are primarily residential land use. The majority of the residential area consists of single-family housing. The estimated residential population density is about 20 people per acre. Commercial land use is about 7%, and the remaining land is made up of a mixture of open space and institutional land uses. In the 909 acre urban study area, there were 51.7 curb miles of public streets.

Hydrologic Features

Climate of the area is under the marine influence of San Francisco Bay and the Pacific Ocean. The Mediterranean climate is characterized by a dry summer followed by a wet winter with irregularly spaced, frontal rainstorms, with over 90% usually occurring between October and April.

Important aspects of the project were dependent on rainfall and resultant runoff. In a normal rain year, there are about 63 days of measurable rainfall. Normal annual rainfall is about 21 inches. During project field activities there were an average of 60 days per year of measurable rainfall with 18 inches the first year and 23.5 inches the second year.

Study Area Characteristics

For this project, the most relevant characteristics of the urban area were: the condition of the street surfaces, the types and conditions of gutters, topography and traffic. Most of the streets were asphalt and in fair condition. The gutters were mainly concrete, and the curbs were mostly vertical (rather than rolled). The upper areas had steep slopes, while the lower study areas were relatively flat. A more detailed description of the study area characteristics is provided in Appendix A.

Average daily traffic (ADT) volumes for the two major arterial streets in the study area were 24,000 vehicles per day for Castro Valley Boulevard (which runs north-to-south) and 19,500 for Redwood Road (which runs west-to-east). ADT volumes for the seven collector streets were about 3500 for the entire urban test area. ADT volumes for the minor residential streets of the urban study area were about 1000.

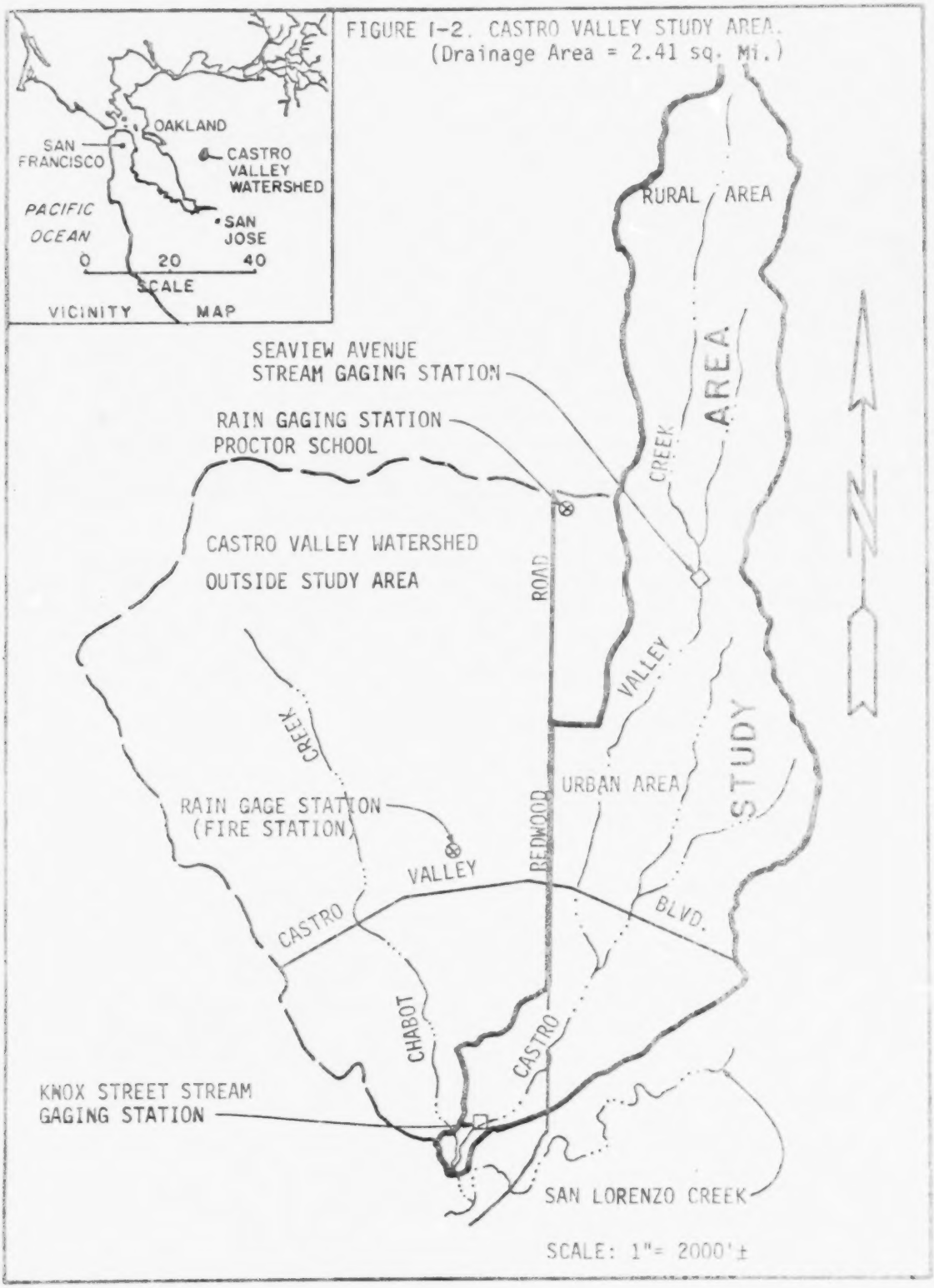


FIGURE I-2. CASTRO VALLEY STUDY AREA.
(Drainage Area = 2.41 sq. Mi.)

Sources of Urban Runoff Pollutants

This section briefly reviews the important sources of urban runoff pollutants. The sources of urban runoff are as many and as varied as the different classifications of land in a watershed. The source that can be controlled by street cleaning is obviously the streets. Road dust and dirt quality is effected by vehicle wear (e.g., brake and clutch linings), drips and spills from vehicles (e.g., gasoline and oils) and exhaust products. It is difficult to identify a small number of activities that contribute most of the significant urban runoff pollutants. Urban landscaping practices potentially affecting urban runoff include vegetation, litter, fertilizer, and pesticide uses. Animal wastes also affect urban runoff quality. Road dust and associated automobile use activities contribute most of the lead in urban runoff. Road dust contaminated by tire wear products contributes most of the zinc to urban runoff. Electroplating or other industrial processing activities contribute cadmium. Much of the mercury released into the environment comes fron natural sources in the Bay area. The relative contribution of each of these potential urban runoff pollutant sources is therefore highly variable, depending on specific site conditions and seasons.

An important information need for urban runoff studies is to know the relative contributions from different pollutant sources in the watershed to the volume of runoff at the outfall or outfall yield. Sources that are further from the storm drainage system require overland flow and have a very low yield of most pollutants when compared with parking lots or street surfaces which are impervious and located adjacent to the drainage system (hydraulically connected).

Street Dust and Dirt Pollutant Sources

Automobile tire wear contributes most of the zinc to urban runoff and it is mostly deposited on street surfaces and adjacent areas. Exhaust particulates, fluid losses, and mechanical wear products can all contribute lead to street dirt.

Automobile exhaust particulates contribute many important metals, the most notable of these being lead. Solomon and Natusch (1977) studied automobile exhaust particulates. They found that the exhaust particulates existed in two distinct morphological forms. The smallest diameters range from 0.2 to 0.5 microns. Because they are small, they can become lodged in the lungs and thus are harmful. The second major form of automobile exhaust particulates are large, being about ten to twenty microns in diameter. They further found that 50 to 100 percent of the emitted lead is associated with these large particles, which would be deposited within a few meters of the emission point onto the roadway because of their aerodynamic properties.

As part of this project, street dirt samples were collected, composited and submitted to a laboratory for chemical analysis. Little variation in chemical quality by season or location was found in the street dirt. Figure 1-3 shows the selected pollutant makeup of one ton of Castro Valley street dirt. The analysis also showed consistency for chemical quality in the different size ranges. The median particle size for the contaminants was several hundred microns. The greater abundance of the larger particulates (in the 200 to 400 micron size range) increases the importance of the larger particle sizes especially because of the ability of street cleaning equipment to particles in this size range.

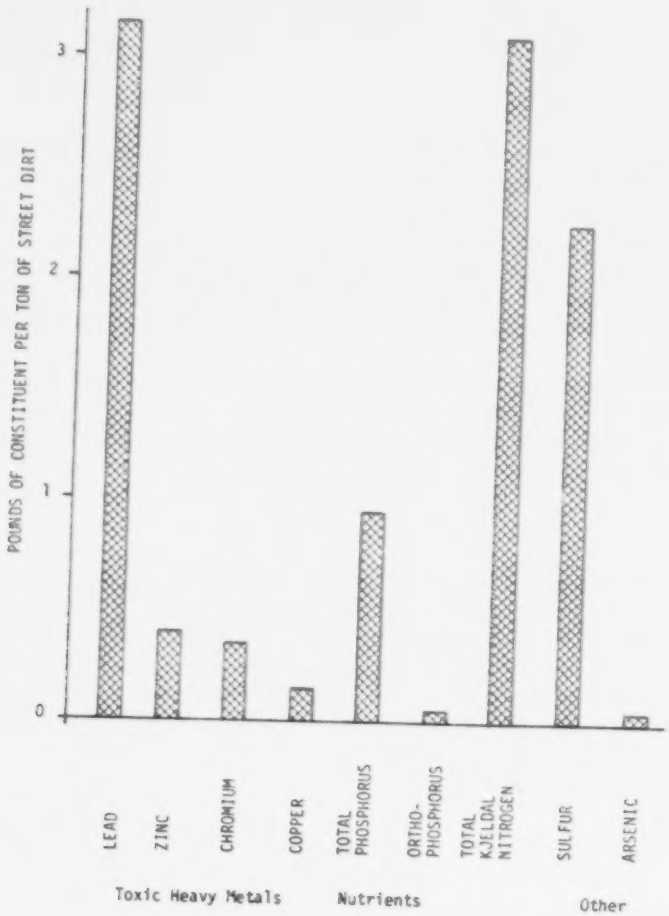


FIGURE 1-3. SELECTED STREET DIRT CHEMICAL QUALITY
CASTRO VALLEY, CA

Receiving Water Measurements

The major objective of this study was to estimte the effects of street cleaning on receiving water quality. An average of about 25 storm periods with an average duration of about two days each occurred in each of the two project years. The durations of the storms ranged fro jusst one hour to as many as 15 days during the test period. the accumulatio periods (i.e., dry periods between storms) rasnged from 12 to 172 dry days preceding each storm. During the first yeat, about 85 percent of the total urban runoff was monitored. During the second year, about 94 percent of the total urban runoff was moniroted. A total of 22 complete datea sets were monitored furing the two year period. A data set was comprised of complete rainfall and runoff monitoring data (quality and quantity) and street surface particulate loading measurements before and after the rain event.

Comparisons of Water Quality with Criteria

One obvious way to determine whether there is a water quality problem in Castro Valley Creek is to compare its water quality concentrations with the various water quality criteria. As Table 1-1 indicates, there is a problem in the creek during wet weather. During base flow conditions (dry weather) there is little difference in the water quality between the rural and urban monitoring stations on the creek. However, during storm water conditions significant removals (control) of pollutants would be necessary in order to meet the standards.

Another method to estimate a possible desirable reduction of pollutants in the runoff is to compare the urban runoff unit area annual discharge to the upstream non-urban area unit discharge. For the urban area unit discharges to correspond to the rural unit area discharges and if "average" reductions are necessary, then about 70% of the nutrients, heavy metals and solids would need to be controlled.

No analyses of dissolved constituents were conducted as part of this study, but some were conducted in Castro Valley Creek from November, 1978 to April, 1979 by Metcalf and Eddy Engineers (Lager, 1979). The earlier monitoring showed that most of the alkalinity and total Kjeldahl nitrogen observed was dissolved, while most of the copper, lead, and zinc was in unsoluble forms. Just because the metals are in insoluable forms does not imply that they are unable to pose potential problems.

Street Cleaner Performance

Most of the street cleaning tests on this project were conducted using a modern, mechanical, four-wheel brush-type street cleaner that had dual gasoline engines and hydraulic controls. The speed during the cleaning program was about five to eight m.p.h. The operating speed of most street cleaners is in the range of four to eight miles per hour. Broom replacement and other maintenance were conducted on a scheduled basis. Because of the nature of this project, the specific operating conditions were held constant during the study program and were not varied.

Castro Valley Street Cleaning Effectiveness

Several street cleaning frequencies were evaluated during the first project year. The second project year, however, used constant street cleaning frequency of 5 times per week for one month followed by two months with no street cleaning operations at all. This enabled the streets to become as dirty as they were likely to become during the first month and then remain at that level during tne second month of no cleaning.

Project results showed that, when the streets were dirtiest (initial loadings of about 1000 or more pounds per curb mile), the cleaning efficiency was about 40%. Even though the range of percentage removal values varies appreciably, the residual (after street cleaning) loading values could not be lower than about 200 pounds per curb mile, even with very intensive cleaning.

After about two to three passes per week, there is very little improvement in either initial or residual street surface loadings. Under these cases, the streets are about as clean as they are likely to get by street cleaning operations and any more frequent street cleaning is unproductive. It is much more cost effective to decrease the street cleaning effort in areas having frequent street cleaning and to increase street cleaning efforts in areas with appreciably diretier streets such as industrial areas.

In addition to evaluating street cleaning frequencies, a comparison was made between two different generic types of equipment. This was done in order to provide information to public works officials concerned about replacing their street cleaners. It is not recommended to change generic types of equipment because there was not enough performance difference observed under the test conditions to justify purchase of one type versus others.

Control of Urban Runoff

This portion summarizes the costs, effectivenesses and potential uses of various urban runoff control measures. Obviously, street cleaning can only be applied to those impervious areas that street cleaning equipment can reach. Inlets and storm sewerage system maintenance can only affect the material that accumulates in them. Treatment at the outfall, however, is capable of affecting pollutants originating from all sources.

Results

The urban runoff yield information was compared to the specific street surface initial loading values for each constituent. This analysis showed that a maximum of about 20 percent of the total solids and about 35 percent of the lead could have been prevented from reaching the receiving water. If maximum urban runoff improvements are going to be realized by street cleaning, then the streets should be cleaned during the winter months between adjacent storm periods. As expected, lead shows the greatest potential for control by street cleaning equipment, followed by total solids and then arsenic. Figure 1-4 illustrates this relationship and further shows that after about three passes per week, any more street cleaning is unproductive.

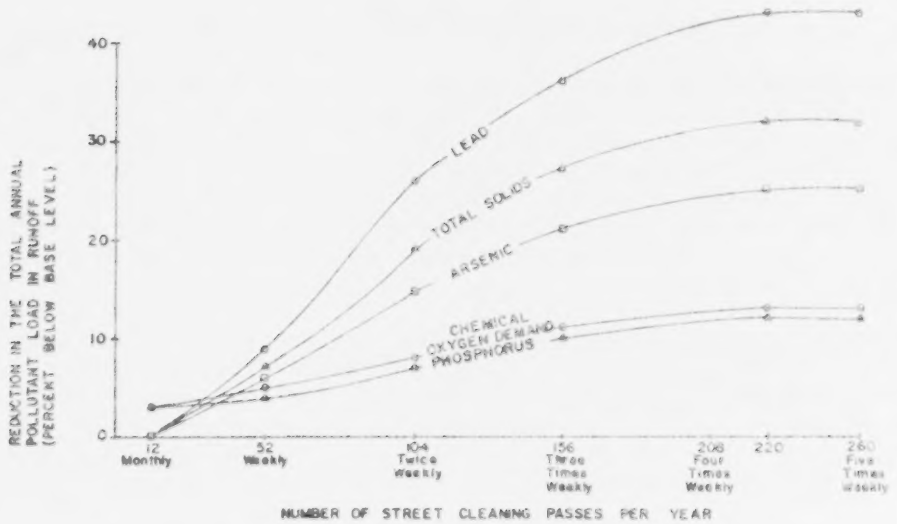


FIGURE 1-4. IMPROVEMENT IN URBAN RUNOFF QUALITY AS A FUNCTION OF STREET CLEANING EFFORT

Total urban runoff control costs could be reduced by at least 25 percent by conducting the most frequent street cleaning efforts immediately before the first rain of the year and during the winter months. Summer street cleaning activities could be substantially reduced in order to meet water quality considerations of street cleaning programs. The cost to remove a unit of contaminant from the street surface increases with increased street cleaning. However, the cost to prevent a unit of contaminant from entering the receiving water did not follow the same pattern during the period of testing. This pattern is very dependent on specific rainfall patterns and for different pollutants.

Figure 1-5 shows that after an initial steep rise in unit cost, going from zero to twice-a-month street cleaning, the unit costs actually decrease. That is, the cost required to prevent a pound of material from reaching the receiving water decreases. After the frequency exceeds about three times per week, however, the unit costs increase again. If the program costs can be justified in terms of water quality, cleaning three times a week between the winter storms may give the best return for the money for total solids. Given the climatic pattern in the Bay Area, it would be more appropriate to schedule the most intensive street cleaning activities before the first major storms of the year, which typically occur in October. The street cleaning effort could then be reduced during the duration of the winter and then significantly reduced during the summer months.

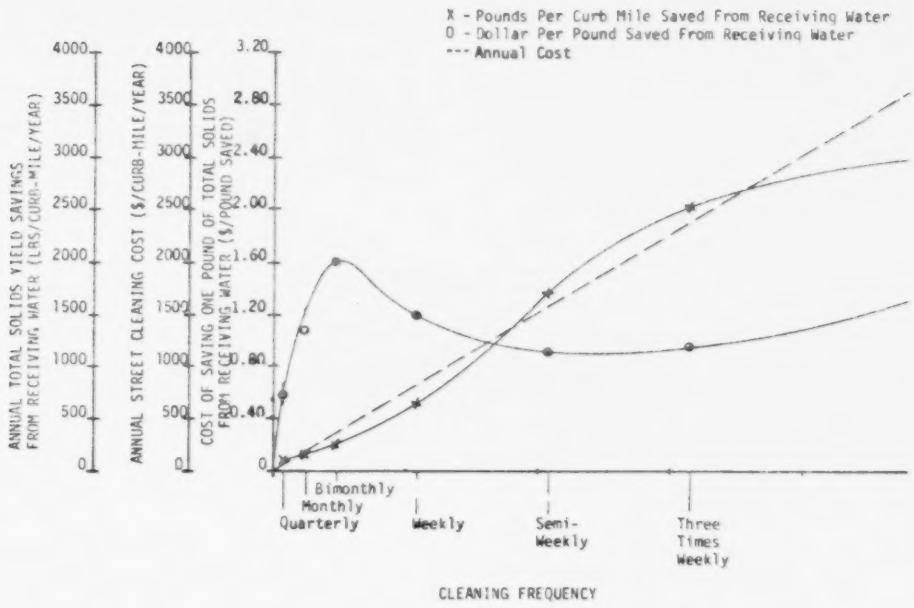


FIGURE 1-5. UNIT COST EFFECTIVENESS OF CONTROLLING URBAN RUNOFF TOTAL SOLIDS BY STREET CLEANING

DESIGN OF STREET CLEANING PROGRAMS FOR WATER QUALITY

This discussion summarizes the procedures that can be used to calculate the effectiveness of street cleaning operations in improving urban runoff quality. Street cleaning unit costs and the use of information from other areas are also briefly described. Simple tables and figures have been prepared to supplement this discussion. These are site specific to various degrees and are the basis for the important calculations in designing a street cleaning program. These figures are based upon observations from the two year Castro Valley NURP Project conducted in Alameda County, CA.

Figure 7-1 shows the accumulation of street surface particulates as a function of exposure time since the last street cleaning or significant rain. There can be significant scatter of the observed data for actual loading conditions. This is because of the effects of wind and traffic causing fugitive dust losses from the street surfaces. In addition, unusual loading conditions may also occur during a testing program caused by spills from trucks, leaves and other vegetative debris and erosion from non-street surfaces areas during light rain events. However, when all the data is carefully reviewed and plotted, general shapes similar to those shown in Figure 7-1 can be produced. The street surface particulate loadings usually increase rapidly soon after the streets are cleaned (0-10 days) or a significant rain, after which they increase at a slower rate. In many parts of the country, such long periods of dry accumulation as occurs in Castro Valley do not exist. The usual two to three week dry spells that are more probable elsewhere result in more straight accumulation curves over shorter periods of time.

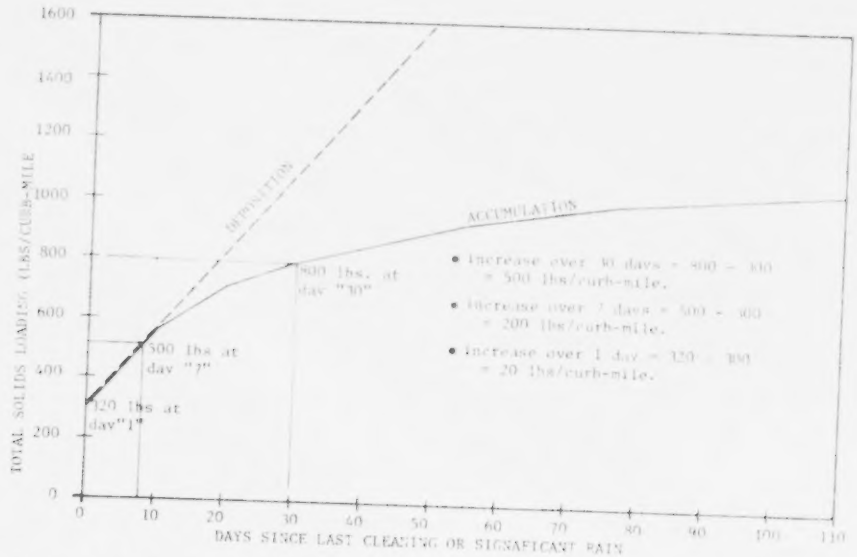


FIGURE 7-1.ACCUMULATION AND DEPOSITION RATES - TOTAL SOLIDS

Figure 7-1 also shows the deposition curve which is tangent to the initial accumulation curve section. This deposition rate is thought to be constant for a specific site and season as it is not dependent upon the loading on the street. However, after about one week the accumulation rate significantly decreases from this deposition rate, with the material not accumulating on the street which is easily lost as fugitive dust due to automobile traffic and high winds. Again, figures such as Figure 7-1 must be prepared for different test area characteristics and seasons. The most important test area characteristics are expected to be geographical i.e., street surface conditions and type, land use and topography. Meteorological conditions are also an important area characteristic that shape the accumulation deposition rate curves.

Figure 7-2 which is also based upon the specific Castro Valley data, relates initial street surface loading values (loadings before the streets are cleaned) to the residual loading values (the loading conditions observed after the streets are cleaned). Figure 7-2 shows the 95% confidence band around the median straight line relationship. This relationship has been found to be dependent mostly on street surface condition and type, land use and season. This relationship is less dependent on other factors such as topography and street cleaning equipment type. Parked car densities can also effect this relationship and should be studied. As shown, the percentage removal of street surface particulates can be high only if the initial street surface loadings are high. When the initial street surface loadings are low, the percentage removal values can be low.

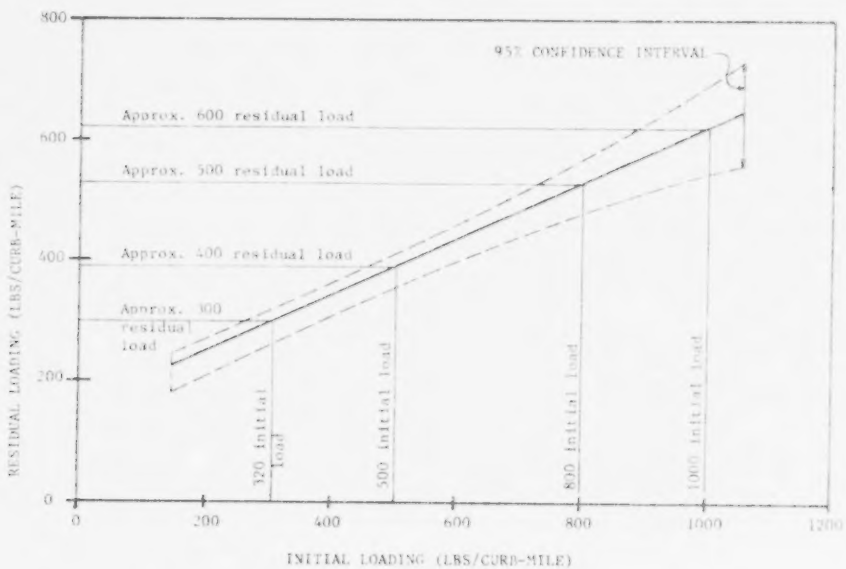


FIGURE 7-2. STREET CLEANER EFFECTIVENESS - TOTAL SOLIDS

Figure 7-3 is extremely site dependent for the Castro Valley Study Area and compares the ratio of the street surface loading values and the runoff yields to the runoff volume during a specific storm event. Figure 7-3 has high "R" squared values (0.80 for lead, 0.91 for total solids, 0.89 for COD and 0.92 for TKN). The "R" squared values for the other constitutents monitored were also quite high approaching 0.98. These relationships of course are extremely site specific and are dependent upon the specific characteristics and erodibilities of the soil particulates and upon street surface particulates. Erosion control practices, landscaping activities and the size of the monitored basins are all thought to change these specific values. Relating the street loading to runoff yield as a ratio to the runoff volume expressed in acre feet per acre instead of just total rainfall observed for a specific storm event resulted in more usable curve as it considers the antecedent dry conditions before each rain event along with the variable intensities of the different rain types.

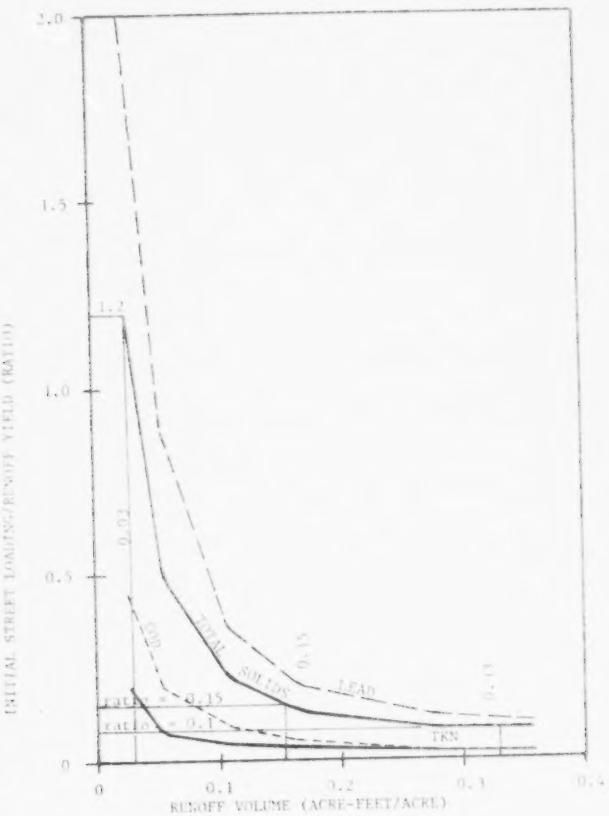


FIGURE 7-3: RUNOFF YIELD COMPARED TO STREET LOADING

When these three figures (7-1, 7-2 and 7-3) are available, a comprehensive methodology is available to determine the effectiveness of street cleaning programs for other time periods and locations studied. This procedure can be very useful in determining the most appropriate street cleaning programs for different service areas and seasons. These procedures can be used to develop street cleaning programs necessary to meet runoff allocation goals, the most cost effecting programs necessary to meet runoff allocation goals or just the appropriation of available street cleaning dollars in the service area. This procedure can also be used to determine when and where service reductions should be made as decreasing budgets warrant.

The first step in this procedure is to determine the accumulation rates between adjacent street cleaning days. Figure 7-1 is marked with three examples for cleaning frequencies of one, seven and thirty days. In all cases, street surfaces have loadings of about 300 lbs. per curb mile after significant rains or after the streets have been cleaned quite frequently. For a one day program, the streets accumulate about 20 lbs. per curb mile between street cleanings, while the loadings can increase to about 500 lbs. per curb-mile between cleanings on a 30-day street cleaning period. These values are shown on Figure 7-4 for these different cleaning frequencies. The resultant residual loadings (after street cleaning) are also shown based upon the values presented in Figure 7-2. This calculation is made for several series of street cleaning and accumulation periods in order to obtain the reasonable range of loadings of street surface particulates. As noted earlier, specific loading values can be much greater or much less than these shown, but these have been found to be quite consistent within the specific test area for a specific season. In all cases, reasonable minimum and maximum values are used in all calculations in order to obtain a reasonable expected range of conditions.

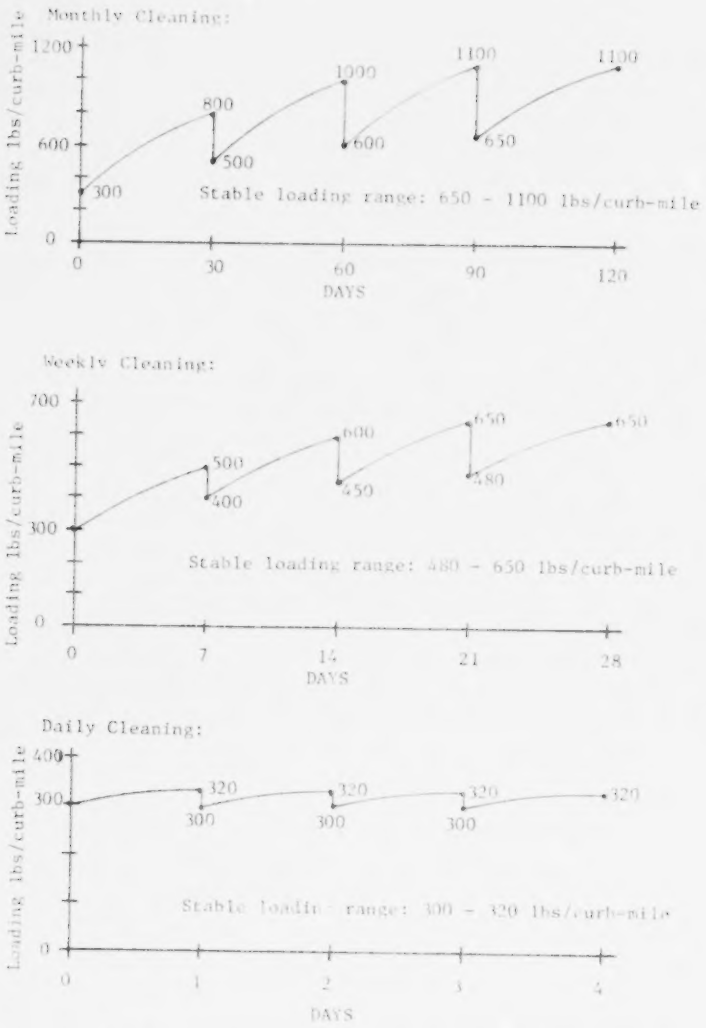


FIGURE 7-4. LOADING VARIATIONS FOR VARIOUS CLEANING PROCESSES. (TOTAL SOLIDS)

Table 7-1 is an example, calculated for a hypothetical season and based upon three probable ranges of street surface loading conditions for these three different street cleaning programs. This hypothetical calculation assumes that there are 10 curb miles in the test basin or service area and also examines a simple selection of only three different storms within the study season. These 3 storms were selected because of their major differences in runoff characteristics and range from the very common small storms for the Castro Valley area to the very rare large storms. This simple calculation examines only one of each of these three storms while an actual calculation must be based upon an actual observed rain record for the season of concern with appropriate calculations for each rain. The ratio of street load to runoff yield for each of these three hypothetical rains was obtained from Figure 7-3, based upon the runoff yield expressed in acre-feet per acre. It is seen that this ratio is large for very small storms, but the ratio is quite small for larger storms. This means that larger storms are mostly made up of non-street surface particulates while smaller storms, because of the reduced hydraulic carrying capacity of the falling water, are only capable of cleansing the directly connected impervious surfaces (mostly streets). In other words, the larger storms are made up of mostly non-street surface erosion products, while the more common smaller storms are mostly made up of street surface particulates and sewerage deposition material. The material that has been deposited in the sewerage during previous large storms is available for transport by some of the smaller storms and most of the larger storms. That is why this ratio is greater than 1.0 for some storms. Table 7-1 uses these street load to runoff yield ratios and the total test area street loadings to obtain the range of runoff yields that can be expected for each of the cleaning programs. Again, in this simple case study these three storm types were added together to solely represent the one season under study. A more reasonable case would require an examination of the complete set of rains expected for an actual season.

TABLE 7-1 TOTAL SOLIDS RUNOFF YIELD FOR VARIOUS CLEANING FREQUENCIES (FOR HYPOTHETICAL RAIN CHARACTERISTICS)

			Cleaning Every One-Day		Cleaning Every 7-days		Cleaning Every 30-days	
	Unit Street Loading (lb/curb-mile) :		300	320	480	650	650	1100
	Total Basin Street Loading (lb.)* :		3000	3200	4800	6500	6500	11000
List of all Storms for Period**	Runoff Yield (acre-ft/ acre)	Street load to Runoff Yield (ratio)	Resultant Runoff Yield	(lb)	Resultant Runoff Yield	(lb)	Resultant Runoff Yield	(lb)
Lrg Storm	0.33	0.1	30,000	32,000	48,000	65,000	65,000	110,000
Med Storm	0.15	0.15	20,000	21,300	32,000	43,300	43,300	73,300
Sml Storm	0.03	1.2	2,500	2,670	4,000	5,400	5,400	9,200
Total Runoff Yield for Period (lbs):			52,500	56,000	84,000	114,000	114,000	193,000

* Assume 10 curb-miles in the basin.

** Example to show effects of different sized storms.

Figure 7-5 is a simple plot of the calculated expected urban runoff yields for this example season for the different street cleaning intervals. This figure shows a band representing the maximum and minimum probable total solids runoff yields. Table 7-2 shows how this figure can be used to calculate the most appropriate street cleaning program, based upon different objectives. This table shows the resultant median runoff yield for this storm period for different types of street cleaning programs along with the resultant runoff load savings and the percent control values. Again, this is for a hypothetical example and the actual control effectiveness are obviously very dependent upon specific site characteristics especially the rainfall conditions during the study period. This table also shows an estimated quarterly program cost for this ten curb mile service area, assuming a unit cost of $15.00 per curb mile. The unit cost, or dollars per pound of runoff pollutant saved, for the different cleaning programs is also shown. In this example, a cleaning frequency of once per week is the most cost-effective, with a resultant cost of about $0.04 per pound of total solids saved from entering the runoff water. If the cleaning frequencey increases to daily cleaning, this can increase by a factor of three or four. If the street cleaning program is practically eliminated (cleaning about once per month) this unit runoff water quality saving cost can be extremely high because of the very ineffective nature of a very low effort street cleaning program.

As mentioned previously, this is an example based upon a very simplified seasonal rainfall set of conditions, but it is also based upon actual observed relationships from Castro Valley. Similar procedures to these were used in the data analyses for calculating the street cleaning effectiveness in the Castro Valley NURP Project. A very complete rain record was obtained and these calculations were made for a broad list of urban runoff constituents. This procedure can be used to optimize existing street cleaning programs, or it can show how programs can either be increased or decreased, depending upon the available resources. This technique would obviously have to be repeated for each service area, and for each season.

By using the procedures herein described, public works officials can calculate the effectiveness of their particular street cleaning operations. These procedures allow development of a strategy for control of urban runoff by providing the calculations to determine the design of street cleaning programs to improve urban runoff quality.

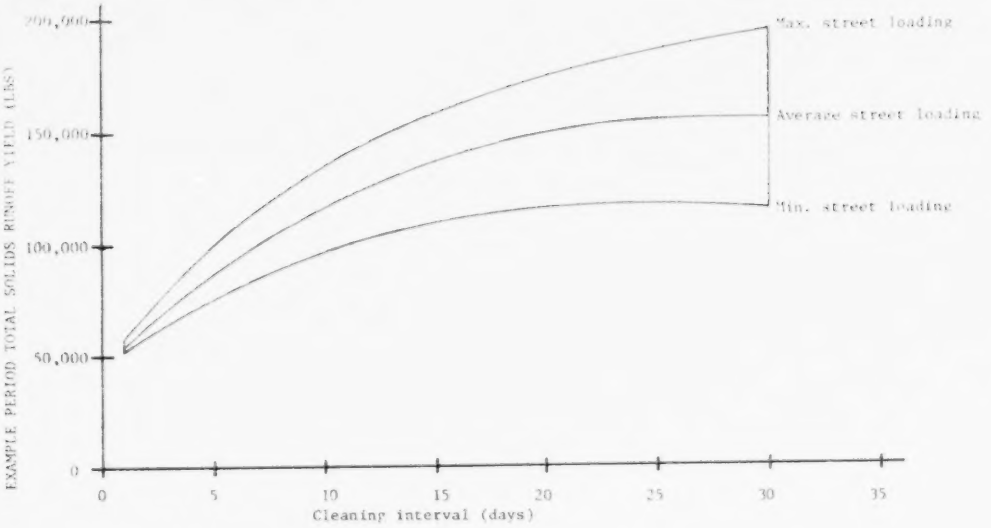


FIGURE 7-5 EXAMPLE PLOT OF RUNOFF YIELD AS A FUNCTION OF CLEANING INTERVAL.

TABLE 7-2. EXAMPLE CALCULATION TO ESTIMATE RUNOFF CONTROL EFFECTIVENESS FOR HYPOTHETICAL RAIN CHARACTERISTICS AND VARIOUS STREET CLEANING FREQUENCY FOR TOTAL SOLIDS

Cleaning Frequency (passes per quarter)*	Cleaning Interval (days)	Runoff Load for Period (lbs)	Runoff Load Savings (lbs)	Percent Control**	Total Quarterly Program Cost ($) ***	Unit Cost ($/lb Runoff Load Savings)
91	1	54,000	101,000	65%	$13,700	0.14
31	3	71,000	84,000	54%	4,600	0.05
13	7	100,000	55,000	35%	2,000	0.04
7	14	134,000	21,000	14%	1,000	0.05
4	21	150,000	5,000	3%	650	0.13
3	30	155,000	0	0	450	0.0
0	91	155,000	0	0	0	--

* Cleaning frequency is a measure of relative program cost.

** As noted, this is for a hypothetical example case. The actual control effectiveness is dependent on specific site characteristics and the rainfall conditions during the period of study. The control effectiveness calculations should be repeated for actual site specific and rainfall conditions.

*** Assuming 10 curb-miles in the Study Area and each pass costs $15.00 per curb-mile cleaned.